DOE/NASA CONTRACTOR REPORT

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INDOOR TEST FOR THE THERMAL PERFORMANCE EVALUATION OF THE DEC 8A LARGE MANIFOLD SUNMASTER EVACUATED TUBE (LIQUID) SOLAR COLLECTOR

Prepared by

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Under Contract DEN-000006

National Aeronautics and Space Administration
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This work was done under the technical management of Mr. B. Wiesenmaier, George C. Marshall Space Flight Center, Alabama.

16. ABSTRACT

This report presents data and test procedures used during the performance of an evaluation test program. The purpose of the test program was to obtian performance data on the Sunmaster DEC 8A Large Manifold solar collector using simulated conditions.

The collector used for this evaluation test was manufactured by Sunmaster Corporation and provided 17.17 square feet of gross collector area. Also included in this report are Test Conditions, Test Requirements, an Analysis of Results, and Tables of Test Data.

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1.0 PURPOSE

The purpose of this document is to present the test procedures used during the performance of an evaluation test program to obtain performance data on the Sunmaster DEC 8A Large Manifold solar collector under simulated conditions.

The test was performed utilizing the MSFC solar simulator in accordance with the test requirements specified in Reference 2.1 and the procedures contained in Reference 2.2, except where noted in the test procedure to accommodate test requirements peculiar to the Sunmaster collector.

2.0 REFERENCES

2.1	ASHRAE 93-77	Method of Testing to Determing the Thermal Performance of Solar Collectors
2.2	MTCP-FA-SHAC-400	Procedure for Operation of the MSFC Solar Simulator Facility
2.3	NASA CR 161306	Indoor Test For Thermal Performance of the Sunmaster Evacuated Tube (Liquid) Solar Collector

3.0 COLLECTOR DESCRIPTION

Manufacturer:	Sunmaster Corporation	
Manufacturer's Address:	12 Spruce Street Corning, New York 14830	
Model Number:	Sunmaster DEC-8A (Large Manifold)	
Serial Number:	DEC-8A 7528 DEC-8A 7529	
Type:	Evacuated Tube	
Working Fluid:	Water	
Gross Collector Area, Ft^2	17.17	
Overall external dimensions:	Width, inches Length, inches Thickness, inches Aperture area, ft^2	48.0 51.5 8.0 14.0
Collector glazing:	Evacuated tube	
Weight:	Empty, lbs. Water Filled, lbs.	65.0 90.0

4.0 SUMMARY

This test program was conducted to evaluate the performance of the Sunmaster DEC 8A Large Manifold liquid, evacuated tube solar collector under simulated conditions. A schematic of the collector array is shown in Figure 1. Thermal performance testing was conducted with the collector mounted to a test table inclined 10° from horizontal. The DEC 8A Large Manifold collector was tested in an open test loop with exit water from the collector dumping in an insulated reservoir after being cooled in a heat exchanger. The test conditions and data obtained for the thermal performance tests of collector serial No. 7528 and collector serial No. 7529 are listed in Table I. Graphic presentation of the thermal performance data is shown in Figure 2. Figure 3 presents a comparison of the thermal performance of the new DEC 8A Large Manifold Sunmaster collector with the reported thermal performance of the original DEC 8A Sunmaster collector from NASA CR161-306. Thermal performance of the new DEC 8A Large Manifold collector is also shown with installation of the original DEC 8 evacuated tubes and reflector and alternately with installation of the original DEC 8 foil covered manifold core. Table II gives test data for the thermal performance of the new DEC 8A Large Manifold collector with installation of the original DEC 8 tubes and reflector while Table III gives test data for the thermal performance of the new DEC 8A Large Manifold collector with installation of the original DEC 8 foil covered manifold core. Thermal performance of the new DEC 8A Large Manifold collector compared with the thermal performance of the original DEC 8 Sunmaster collector is graphically presented in Figure 4. Also shown in Figure 4 is the slightly improved thermal performance of the new DEC 8A Large Manifold collector with the original DEC 8 tubes installed. Table IV contains thermal performance data for the retest of the original DEC 8 Sunmaster collector. Table V gives test data for new DEC 8A Large Manifold collector thermal performance with the DEC 8 evacuated tubes installed.

A time constant test was not performed for the DEC 8A Large Manifold collector. It is assumed that the time constant of 12 mintues at a .175 GPM flow rate, reported in NASA CR 161306, for the original DEC 8A collector, is also representative of the new DEC 8A Large Manifold Collector. Two seperate incident angle modifier tests were performed to determine the transient effects of solar incidence angle on the collector. The results of the standard east/west incident angle modifier and the altitude angle incident angle modifier tests are shown in Figures 5 and 6, respectively. Table VI contains standard east/west incident angle modifier test data for the new DEC 8A Large Manifold collector while Table VII contains the altitude angle incident angle modifier data.

5.0 Test CONDITIONS AND TEST EQUIPMENT

5.1 Ambient Conditions

Unless otherwise specified herein, all tests were performed at ambient conditions existing in Building 4619 at the time of the tests.

5.2 Instrumentation and Equipment

All test equipment and instrumentation used in the performance of this test program comply with the requirements of MSFC-MMI-5300.4C, Metrology and Calibration. A listing of the equipment used in each test follows.

Apparatus	Manufacturer/Model	Range/Accuracy
Pyranometer	Eppley - PSP	0-800 $BTU/Ft^2 \cdot Hr$ Class I
Liquid Loop	MSFC Supplied	.1 - 1.2 GPM
Directional Anemometer	Supplied by AMC	0 - 30 MPH
Flow Meter	Fischer & Porter Co. / Rotameter	.1 - 1.12 ± 1% GPM
Thermocouples	Type E	(-100) - 700 ± .1°F
Strip Chart Recorder	Mosley 680	5-500 MV ± 2%
Fans	MSFC Supplied	N/A
Solar Simulator	MSFC Supplied	See SHC 3006
Data Logger	Model 2240A / John Fluke Company	1 - 30 mv ± .01%

All transducers, with the exception of the Eppley PSP pyranometer used in recording test data, are calibrated by either NASA or AMC calibration laboratories as required by MSFC-MMI-5300.4C. The PSP pyranometer was calibrated by the manufacturer. The stated accuracy of individual transducers reflects the overall expected accuracy through the data acquisition system.

5.0 TEST CONDITIONS AND TEST EQUIPMENT (Continued)

5.3 Data Systems

A John Fluke Company Model 2240A output data logger was used to record all test data. A formal systems error analysis was not done; confidence in printout accuracies was established by installing calibrated "parallel" transducers to take direct readouts at key points in the system. Comparison checks were performed from time to time before, during, and after tests. The results of such checks together with a review of the data for anomalies indicated that the data presented is suitable for the purpose intended.

6.0 <u>TEST REQUIREMENTS AND PROCEDURES</u> (Continued)

6.1 Collector Thermal Efficiency Test

6.1.1 Requirements

Utilizing the MSFC Solar Simulator and the portable liquid loop, parametric performance evaluation data shall be recorded of the following test variables and conditions. The liquid to be used is the manufacturer's recommended heat transfer fluid. If not specified, the test shall be performed using water as the working fluid.

Variable/Condition	Requirement
(1) Collector inlet liquid temperature differential above existing ambient temperature level	0^oF, 25^oF, 50^oF, 75^oF and 100^oF
(2) Collector outlet liquid temperature	Measured data
(3) Incident solar flux level	200 to 300 $BTU/Hr \cdot Ft^2$
(4) Liquid flow rate through collector	.175 GPM
(5) Wind speed	7.5 MPH
(6) Ambient air temperature	Existing room condition

6.1.2 Procedure

1. Mount test specimen on test table at a 10^o angle with reference to the floor.
2. Assure that simulator lamp array is adjusted to an angle of 10^o with reference to the floor.
3. Using the procedure contained in Reference 2.2, align the test table so the test specimen's vertical centerline coincides with the vertical centerline of the lamp array and the distance from the center of the test specimen to the lens plane of the lamp array is 9 feet.
4. Insulate all liquid lines.
5. Connect instrumentation leads to data acquisition system.
6. Assure that data acquisition system is operational.

6.0 TEST REQUIREMENT AND PROCEDURES (Continued)

6.1 Collector Thermal Efficiency Test (Continued)

6.1.2 Procedure (Continued)

7. Perform sensor accuracy verification tests.

8. Establish required wind speed.

9. Start liquid flow loop and establish the required flow rate.

10. Establish the required inlet temperature

11. Power up solar simulator in accordance with Reference 2.2 and establish the required solar flux level, performing a flux map at top, middle and bottom of each tube.

12. Record data for a minimum of ten minutes at these stablizied conditions.

13. Repeat Steps 9 through 12 for all inlet temperatures.

14. Upon completion of testing, power down simulator and liquid loop in accordance with Reference 2.2.

6.1.3 Results

The results of the thermal performance test of the new DEC 8A Large Manifold collector are contained in Table I for collector serial No. 7528 and serial No. 7529. Figure 2 graphically presents the thermal performance data for collector serial No. 7528 and collector serial No. 7529. Table II gives results for the thermal performance of the new DEC 8A Large Manifold collector with installation of the original DEC 8 evacuated tubes and reflector while Table III gives results of the performance of the new DEC 8A Large Manifold collector with installation of the original DEC 8 foil covered manifold core. Figure 3 graphically compares the thermal performance results for the new DEC 8A Large Manifold collector with the thermal performance of the original DEC 8A collector (Ref.2.3) and shows thermal performance results for installation of the above mentioned original DEC 8 components with the new DEC 8A Large Manifold collector. Table IV contains thermal performance data for a retest of the original DEC 8 Sunmaster collector. Table V gives results for the new DEC 8A Large Manifold

6.0 <u>Test Requirements and Procedures</u> (Continued)

6.1.3 <u>Results</u>

thermal performance with the Original DEC 8 evacuated tubes installed. Figure 4 graphically compares the thermal performance results for the new DEC 8A Large Manifold collector with the thermal performance of the original DEC 8 collector and shows improved thermal performance with the installation of the original DEC 8 tubes in the new DEC 8A Large Manifold collector.

6.0 TEST REQUIREMENTS AND PROCEDURES (Continued)

6.2 Incident Angle Modifier Test

6.2.1 Test Requirements (Standard East/West)

Due to flow and drain down requirements, the collector could not be tilted; therefore, the lamp array was adjusted to 10^{o}, 20^{o}, 30^{o}, 40^{o} and 50^{o} with respect to the solar collector surface. The liquid flow rate shall be 0.175 GPM with the inlet temperature controlled to within $\pm$ 2^{o}F of ambient. The insolation rate shall be 300 BTU/FT^2·hr. The liquid to be used is the manufacturer's recommended fluid. If not specified, the tests shall be performed using water as the heat transfer medium. The following data shall be recorded during the tests:

(1) Lamp array tilt angles.

(2) Ambient air temperature.

(3) Collector inlet liquid temperature.

(4) Collector outlet liquid temperature.

(5) Collector differential temperature.

(6) Liquid flow rate through the collector.

(7) Incident solar flux level.

6.2.2 Procedure (Standard East/West)

1. Set up lamp array at required tilt angle.
2. Establish required flowrate.
3. Establish required inlet temperature.
4. Establish solar simulator flux level at 300 BTU/Ft^2·Hr and measure the flux levels at 24 locations on the collector surface and record on data sheet.
5. Record data for ten minutes at above stabilized conditions.

6.2 Test Requirements (Altitude Angle Incident Angle Modifier)

The collector altitude angle incident angle modifier shall be determined by tilting the solar simulator array at an

6.0 TEST REQUIREMENTS AND PROCEDURES (Continued)

6.2 Incident Angle Modifier Test (Continued)

6.2.3 Test Requirements (Altitude Angle Incident Angle Modifier)

altitude angle of 10^{o}, 20^{o}, 30^{o}, and 40^{o} with respect to the verticle axis of the collector. The liquid flow rate shall be 0.175 GPM with the inlet temperature controlled to within $\pm$ 2^{o}F of ambient. The insolation rate shall be 300 BTU/Ft^2·hr. The tests shall be performed using water as the heat transfer medium. The following data shall be recorded during the tests:

(1) Lamp array tilt angles.

(2) Ambient air temperature.

(3) Collector inlet liquid temperature

(4) Collector outlet liquid temperature.

(5) Collector differential temperature.

(6) Incident solar flux level

(7) Liquid flow rate through the collector.

6.2.4 Procedure (Altitude Angle Incident Angle Modifier)

(1) Set up lamp array at required tilt angle.

(2) Establish required flow rate.

(3) Establish required inlet temperature

(4) Establish solar simulator flux level at 300 BTU/Ft^2 hr and measure the flux level at 24 locations on the collector surface.

(5) Record data for ten minutes at above stabilized conditions.

(6) Repeat above steps as necessary to obtain required data for each tilt angle.

6.0 TEST REQUIREMENTS AND PROCEDURES (Continued)

6.2 Incident Angle Modifier Test (Continued

6.2.5 Results

The results of the standard east/west incident angle modifier and the altitude incident angle modifier tests are shown in Figure 5 and 6, respectively. Table VI contains standard east/west incident angle test data for the new DEC 8A Large Manifold collector while Table VII contains the altitude angle incident angle modifier data.

7.0 ANALYSIS OF RESULTS

7.1 Thermal Performance Test

The analysis of data contained in this report is in accordance with the procedures of References 2.1 and 2.2 The thermal efficiency of the new DEC 8A Large Manifold collector determined from test data in Table I is given by the following equation:

$$\eta = .400 - .191 \left(\frac{T_i - T_a}{I}\right) \text{ based on gross collector area.}$$

where:

η = collector efficiency based on gross collector area.

I = Total solar energy incident upon the plane of the solar collector per unit time per unit area ($BTU/Hr \cdot Ft^2$).

T_a= Temperature of the ambient air surrounding the collector (^oF).

T_i= Temperature of the transfer liquid entering the collector (^oF).

The procedure for calculating thermal efficiency as outlined in ASHRAE 93-77 is adequate for indoor testing of the new DEC 8A Large Manifold collector due to the fact that true "steady state" conditions can be achieved. The calculated values of efficiency were determined at sixty-second intervals. The mean value of efficiency was determined over a ten mintue period during which the test conditions remained at steady state. Each ten-minute period constitutes one "data point" as is graphically depicted on a plot of percent efficiency versus

$(T_i - T_a)/I$

The abscissa term $(T_i - T_a)/I$ was used to normalize the effect of operating at slightly different values of I, T_i and T_a. The results are found in Figure 2. Due to the excellent insulative properties of the evacuated tube, the best curve fit is a first order polynomial given by:

Efficiency = $a_0 + a_1$ P

7.0 ANALYSIS (Continued)

7.1 Thermal Performance Test (Continued)

where:

$$P = (T_i - T_a)/I$$

and the coefficients are determined to be:

a_0	0.400	DEC 8A Large Manifold Collector
a_1	-0.191	

Figure 4 shows slightly improved performance when the original DEC 8 tubes are substituted.

Then the coefficients are determined to be:

a_0	0.412	DEC 8A Large Manifold Collector with original DEC 8 tubes.
a_1	-0.191	

7.0 ANALYSIS (Continued)

7.2 Incident Angle Modifier Test

Two methods are proposed by ASHRAE 93-77 for incident angle modifier tests. For the MSFC Solar Simulator Facility, only method 1 (Tilting the collector) is applicable. However, due to the flow and drain down design of this collector, it was necessary to tilt the solar array instead of the collector. The lamp array could not be adjusted to 60°; therefore, the angles of 10°, 20°, 30°, 40°, and 50° to the normal of the collector surface were used.

According to 93-77, the incident angle modifier is defined as

$$K_{\alpha\tau} = \frac{\eta}{(A_a/A_g)\ F_R\ (\tau\alpha)_n} \qquad (1)$$

where η = efficiency at tilted angle and

$(A_a/A_g)F_R(\tau\alpha)_n$ = Intercept of efficiency curve at normal incident angle, = 0.400 for the new DEC 8A Large Manifold collector.

For equation (1) to be applicable, the inlet liquid temperature must be controlled to within $\pm$ 2°F of the ambient air temperature. In cases where the inlet liquid temperature cannot be controlled to within $\pm$ 2°F, the following equation must be used to evaluate the incident angle modifier.

$$K_{\alpha\tau} = \frac{\eta + (A_a/A_g)F_RU_L \dfrac{T_i - T_a}{I}}{(A_a/A_g)\ F_R(\tau\alpha)_n} \qquad (2)$$

where

$(A_a/A_g)F_RU_L$ is the negative of the slope determined from the thermal efficiency curve, =-0.191 for the new DEC 8A Large Manifold collector.

Tables VI and VII show that the inlet liquid temperatures were all within $\pm$ 2°F of ambient air temperature, for both the standard east/west incident angle modifier and the altitude incident angle modifier data. Hence equation (1) was used for evaluation.

$$K_{\alpha\tau} = \frac{\eta}{0.400}$$

7.0 ANALYSIS (Continued)

7.2 Incident Angle Modifier Test (Continued)

The results of computations are shown on Tables VI and VII and plotted against incident angle in Figures 5 and 6 for the standard east/west incident angle modifier and the altitude angle incident angle modifier, respectively.

The purpose of the incident angle modifier is to allow a designer or analyst to predict the total daily energy output from the collector, as the sun tracks from east to west. Most collectors are more efficient at normal incidence than at other angles, but some are even more efficient at angles other than normal. The only common ground for comparing collectors should be the "all day efficiency" rather than $F_R(\tau\alpha)_n$. However, the prospective application of the collector also influences the value of "all day efficiency." That is, for low temperature applications such as space heating or domestic hot water, a typical flat plate collector may have an all day efficiency of 40%, but for solar cooling applications the all day efficiency might be 20%.

TABLE I

THERMAL PERFORMANCE TEST DATA
FOR THE NEW DEC-8A LARGE MANIFOLD SUNMASTER COLLECTOR

	Collector Serial No. 7528						Collector Serial No. 7259					
Ambient Air Temp (Ta), °F	51.8	53.2	64.8	53.9	67.6	63.3	63.7	66.3	67.0			
Fluid Inlet Temp (Ti), °F	50.2	76.8	90.0	106.8	129.4	176.0	73.5	112.2	155.0			
Fluid Outlet Temp (Te), °F	69.1	95.2	108.0	124.3	146.1	191.3	90.7	128.5	170.2			
Differential Fluid Temperature (ΔT), °F	19.0	18.4	18.0	17.5	16.7	15.3	17.2	16.3	15.2			
Total Solar Flux (I), $BTU/Hr \cdot Ft^2$	306.31	306.31	299.67	306.31	299.67	299.62	277.07	282.96	282.96			
Flow Rate lbm/hr	110.44	110.28	110.28	109.24	109.93	109.92	110.28	109.98	109.90			
(Ti - Ta)/I $°F \cdot Hr \cdot Ft^2/BTU$	-.005	.077	.084	.173	.206	.376	.035	.162	.311			
Efficiency (η)	.399	.386	.386	.363	.357	.327	.399	.369	.344			

TABLE II

THERMAL PERFORMANCE TEST DATA
FOR THE NEW DEC 8A SUNMASTER LARGE MANIFOLD COLLECTOR
WITH THE ORIGINAL DEC 8 TUBES AND REFLECTOR

Ambient Air Temp (Ta), ^oF	84.6	82.0	84.5	85.7	83.3							
Fluid Inlet Temp (Ti), ^oF	84.2	83.3	115.0	143.0	166.0							
Fluid Outlet Temp (Te), ^oF	101.2	100.5	131.5	158.0	181.2							
Differential Fluid Temperature (ΔT), ^oF	17.0	17.2	16.5	15.0	15.2							
Total Solar Flux (I), $BTU/Hr \cdot Ft^2$	270.62	273.00	273.00	270.62	281.4							
Flow Rate lbm/hr	109.93	109.93	109.90	109.77	109.64							
(Ti - Ta)/I $^oF \cdot Hr \cdot Ft^2/BTU$	-.001	.005	.112	.212	.293							
Efficiency (η)	.402	.403	.387	.354	.345							

TABLE III

THERMAL PERFORMANCE TEST DATA
FOR THE NEW DEC-8A Large MANIFOLD SUNMASTER COLLECTOR
WITH THE ORIGINAL DEC-8 FOIL COVERED MANIFOLD CORE

Ambient Air Temp (Ta), ^{o}F	82.7	77.9	79.2	80.7	80.1							
Fluid Inlet Temp (Ti), ^{o}F	86.6	86.2	120.1	156.0	177.1							
Fluid Outlet Temp (Te), ^{o}F	103.9	103.3	136.5	171.2	191.8							
Differential Fluid Temperature (ΔT), ^{o}F	17.3	17.1	16.4	15.2	14.7							
Total Solar Flux (I), $BTU/Hr \cdot Ft^2$	285.57	279.58	279.58	279.58	279.58							
Flow Rate lbm/hr	109.93	109.93	109.90	109.77	109.64							
(Ti - Ta)/I $^{o}F \cdot Hr \cdot Ft^2/BTU$	.0136	.0297	.1462	.2693	.3469							
Efficiency (η)	.388	.392	.375	.348	.336							

TABLE IV

THERMAL PERFORMANCE TEST DATA
FOR RETEST OF THE ORIGINAL DEC8 SUNMASTER COLLECTOR

Ambient Air Temp (Ta), ^oF	69.9	73.0	73.5									
Fluid Inlet Temp (Ti), ^oF	70.0	118.4	161.0									
Fluid Outlet Temp (Te), ^oF	89.0	136.1	177.7									
Differential Fluid Temperature (ΔT), ^oF	19.0	17.7	16.7									
Total Solar Flux (I), $BTU/Hr \cdot Ft^2$	296.74	296.74	296.74									
Flow Rate lbm/hr	110.44	110.44	109.90									
(Ti - Ta)/I $^oF \cdot Hr \cdot Ft^2/BTU$	.000	.1530	.2949									
Efficiency (η)	.412	.384	.360									

TABLE V

THERMAL PERFORMANCE TEST DATA
FOR THE NEW DEC 8A LARGE MANIFOLD SUNMASTER COLLECTOR
WITH THE ORIGINAL DEC8 TUBES

Ambient Air Temp (Ta), °F	74.8	68.2	71.4	71.5	63.0	65.7	67.0	71.5	76.6			
Fluid Inlet Temp (Ti), °F	74.3	74.4	97.8	76.0	72.8	111.7	155.0	115.6	155.3			
Fluid Outlet Temp (Te), °F	91.8	91.3	114.0	93.2	90.0	127.9	169.9	132.4	171.4			
Differential Fluid Temperature (ΔT), °F	17.5	16.9	16.2	17.2	17.2	16.2	14.9	16.8	16.1			
Total Solar Flux (I), BTU/Hr·Ft^2	275.27	270.46	273.29	273.61	275.73	275.73	275.73	279.51	286.80			
Flow Rate lbm/hr	110.27	111.50	110.38	110.88	110.27	110.27	109.90	110.27	109.90			
(Ti - Ta)/I °F·Hr·Ft^2/BTU	-.0018	.0229	.0966	.0164	.0355	.1668	.3191	.1578	.2774			
Efficiency (η)	.408	.406	.381	.406	.401	.377	.346	.386	.359			

TABLE VI

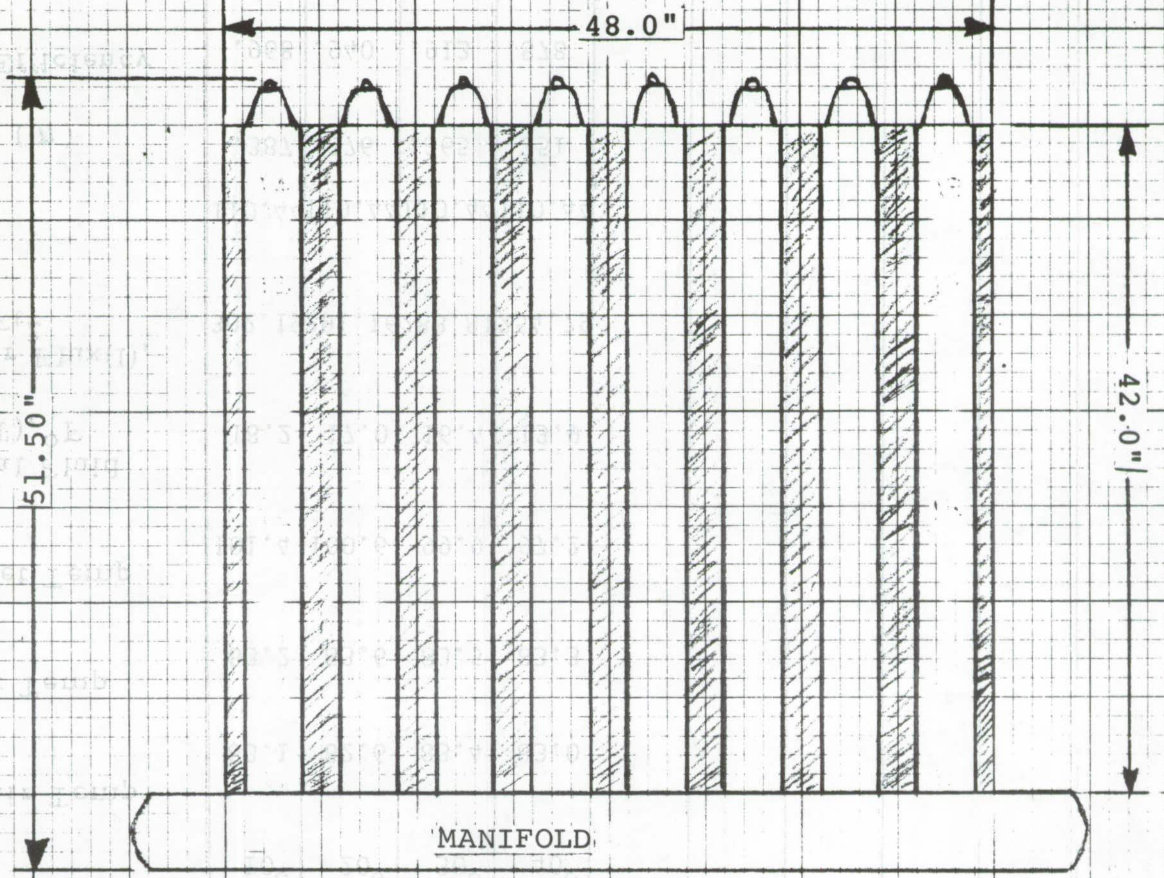
INCIDENT ANGLE MODIFIER TEST DATA
FOR THE NEW DEC 8A LARGE MANIFOLD SUNMASTER COLLECTOR
SERIAL NO 7528

Angle	10^{o}	20^{o}	30^{o}	40^{o}	50^{o}							
Ambient Air Temp (Ta), ^{o}F	52.4	49.2	49.1	50.3	48.9							
Fluid Inlet Temp (Ti), ^{o}F	51.0	49.2	50.2	50.4	48.6							
Fluid Outlet Temp (Te), ^{o}F	70.4	66.5	67.0	66.6	62.0							
Differential Fluid Temp (ΔT), ^{o}F	19.4	17.3	16.8	16.2	13.4							
Total Solar Flux(I), $BTU/Hr \cdot Ft^2$	300.01	262.91	237.22	226.00	192.81							
Flow Rate lbm/hr	110.44	110.44	110.44	110.44	110.44							
Efficiency (η)	.416	.423	.456	.461	.447							
Adjusted Efficiency Ratio $K_{\alpha\gamma}$	1.040	1.058	1.140	1.153	1.118							

TABLE VII

ALTITUDE ANGLE INCIDENT ANGLE MODIFIER
FOR THE NEW DEC 8A LARGE MANIFOLD SUNMASTER COLLECTOR

Angle	10^{o}	20^{o}	30^{o}	40^{o}								
Ambient Air Temp (Ta), ^{o}F	83.1	82.6	83.4	83.0								
Fluid Inlet Temp (Ti), ^{o}F	83.2	83.6	83.5	83.3								
Fluid Outlet Temp (Te), ^{o}F	101.4	100.6	99.9	97.2								
Differential Fluid Temp (ΔT), ^{o}F	18.2	17.0	16.4	13.9								
Total Solar Flux(I), BTU/Hr$\cdot$ Ft^2	302.19	291.16	288.81	254.79								
Flow Rate lbm/hr	110.44	110.44	110.44	110.44								
Efficiency (η)	.387	.376	.365	.351								
Adjusted Efficiency Ratio $K\alpha\gamma$	.968	.940	.913	.878								



Reflective Surface   Area Gross = 17.17 ft^2

Area Aperature = 14.0 ft^2

Figure 1. Schematic of the Sunmaster Collector DEC 8A Large Manifold

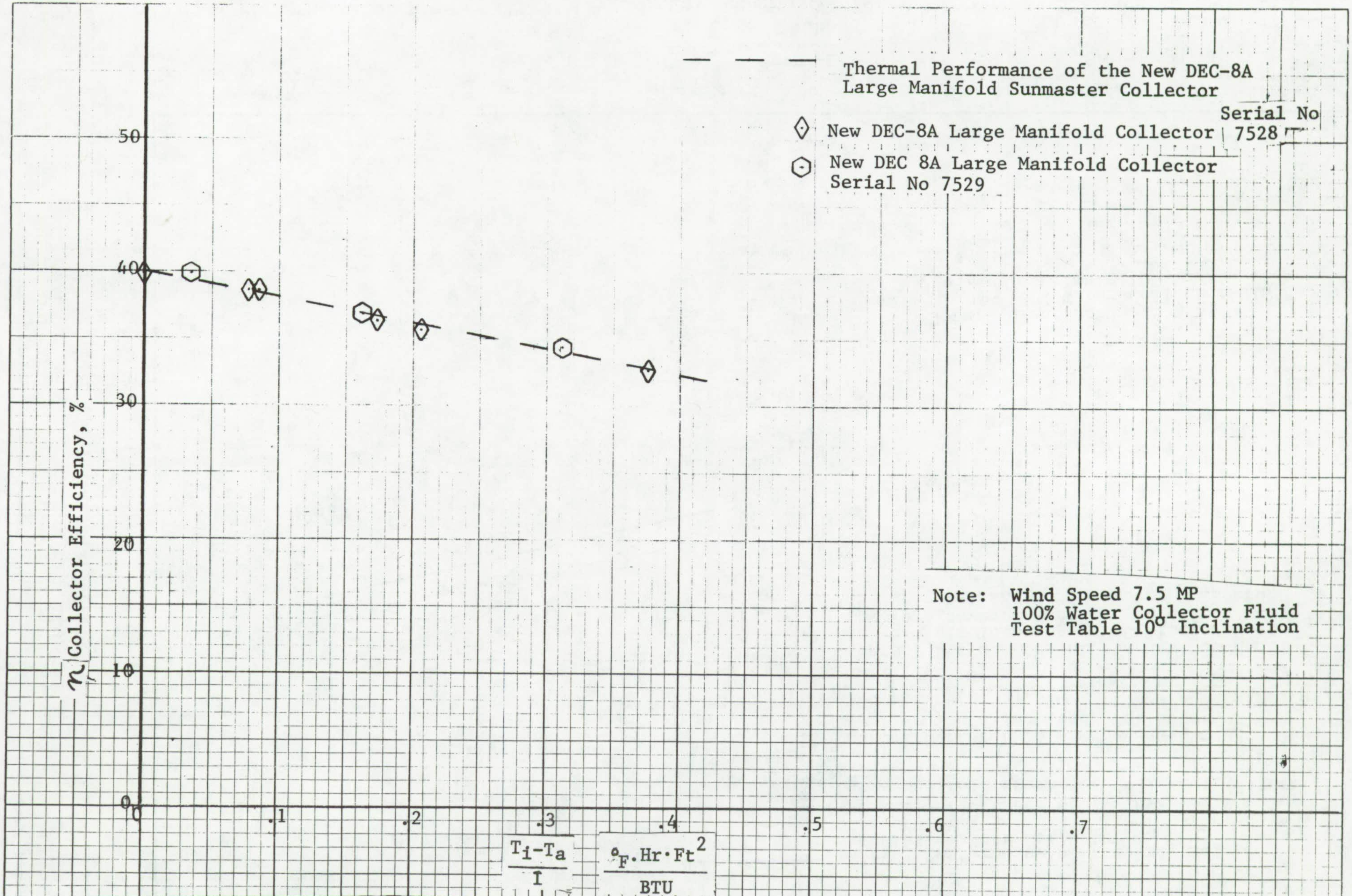


Figure 2. Thermal Performance of the new DEC 8A Large Manfiold Sunmaster Collector

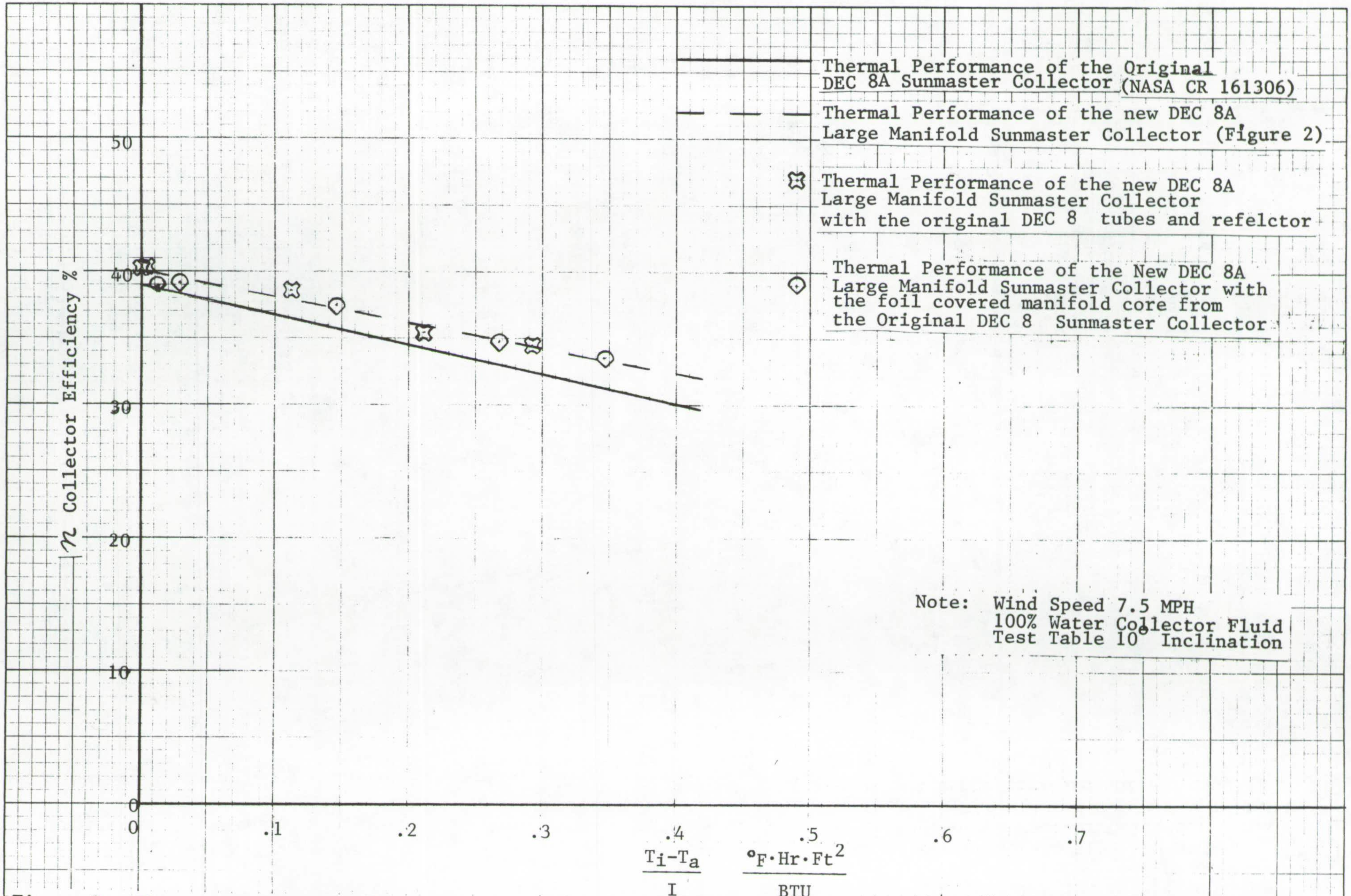


Figure 3. Thermal Performance of the New DEC 8A Large Manifold Sunmaster Collector with installation of the Original DEC 8 tubes and reflector and alternately with installation of the Original DEC 8 foil covered manifold core.

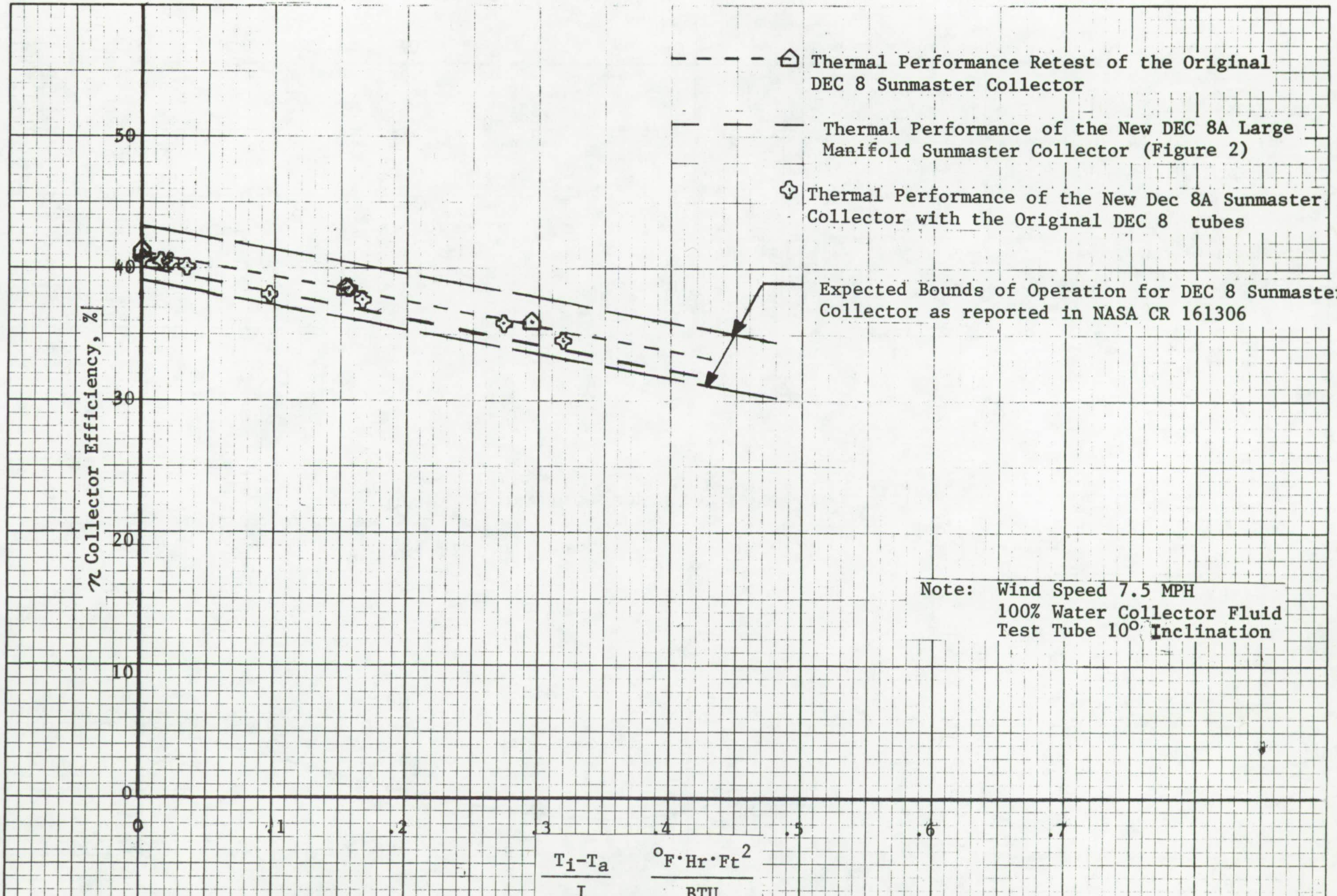


Figure 4. Thermal Performance of the New DEC 8A Large Manifold Sunmaster Collector compared with the Thermal Performance of the Original DEC 8 Sunmaster Collector

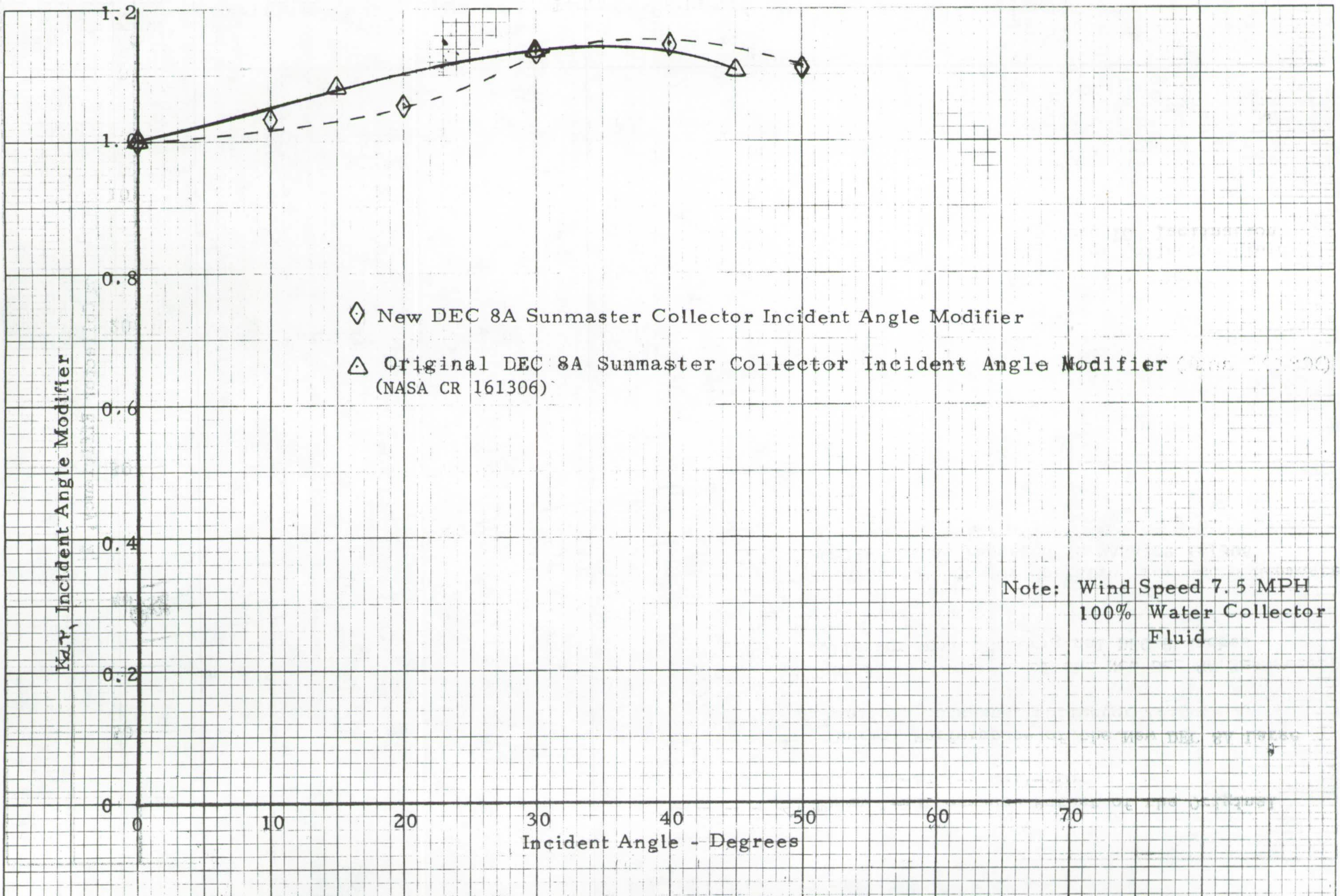


Figure 5. Incident Angle Modifier of the New DEC 8A Large Manifold Collector.

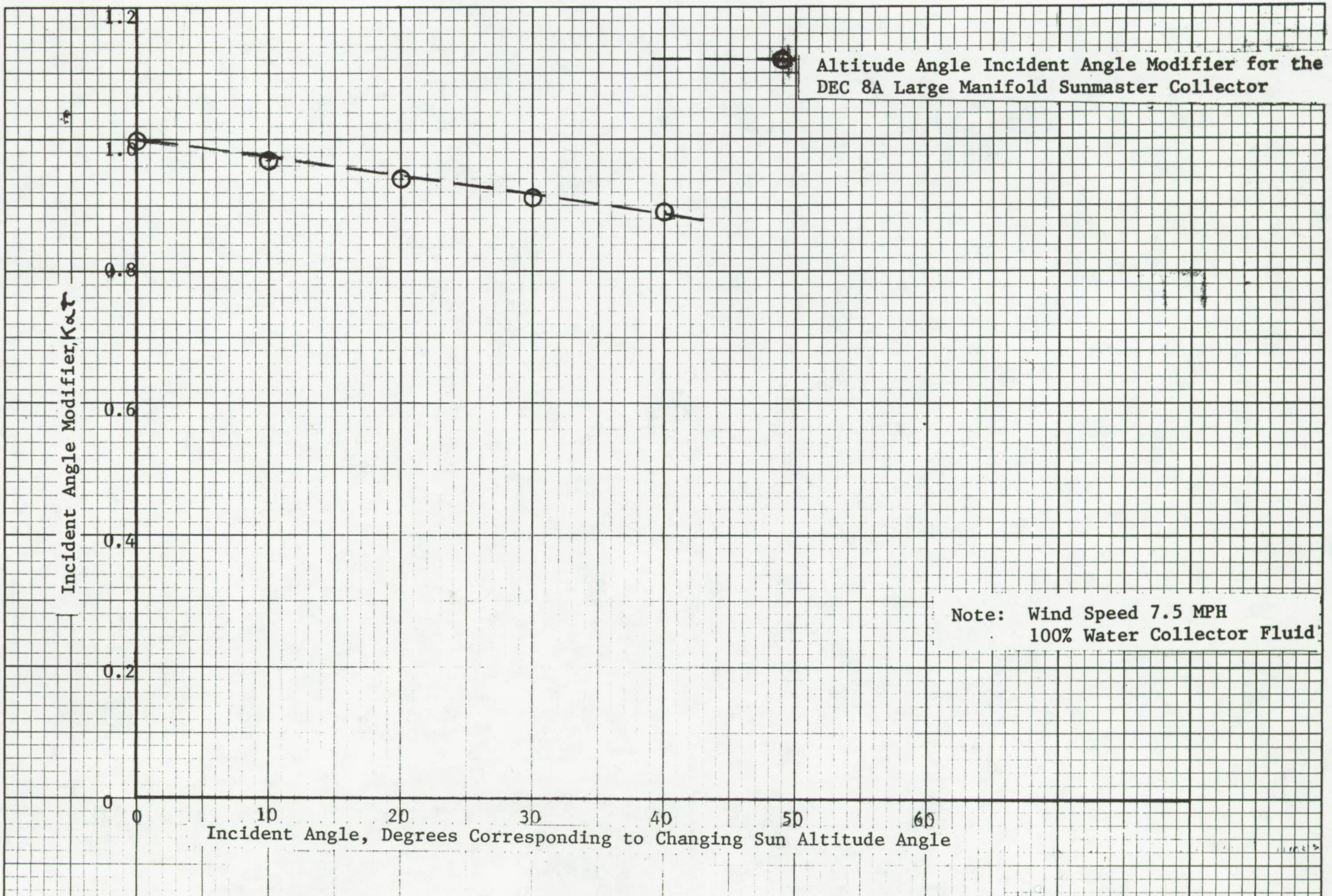


Figure 6. Altitude Angle Incident Modifier for the New DEC 8A Large Manifold Sunmaster Collector